AD/A-000 570

NEAR FIELD SMALL EARTHQUAKE STRONG MOTION STUDIES

Mihailo D. Trifunac

California Institute of Technology

Prepared for:

Air Force Office of Scientific Research
Advanced Research Projects Agency

31 July 1974

Form Approved
Budget Bureau No. 22-R0293

Semi-Annual Technical Report

1 January - 31 July 1974

prepared at

Earthquake Engineering Research Laboratory
California Institute of Technology
Pasadena, California 91109

(1) ARPA Order 2134

(2) Program Code 3F10

(3) California Institute of Technology

(4) Contract effective: 30 June 1972

(5) Contract expires: 31 July 1975

(6) $147, 642

(7) F44620-72-C-0097

(8) Mihailo D. Trifunac
Assistant Professor of Applied Science
(213) 795-6811, Ext. 1160

(9) Mihailo D. Trifunac

(10) Near Field Small Earthquake-Strong Motion Studies

Sponsored by

Advanced Research Projects Agency
ARPA Order No. 2134

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D AD/A-000570

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) California Institute of Technology Earthquake Engineering Research Laboratory Pasadena, California 91109	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Near Field Small Earthquake Strong-Motion Studies

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific Interim

5. AUTHOR(S) (First name, middle initial, last name)

M. D. Trifunac

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
	21	

8a. CONTRACT OR GRANT NO. F44620-72-C-0097	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. AO 2134	
c. 62701E	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFOSR - TR - 74 - 1755
d.	

10. DISTRIBUTION STATEMENT

Approved for public release, distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
TECH, other	AF Office of Scientific Research (NPG) 1400 Wilson Boulevard Arlington, VA 22209

13. ABSTRACT

The objective of the Joint Experiment on Earthquake Source Spectra is to improve our ability to distinguish between the explosive and tectonic energy releases in the magnitude range 3≤M≤5. Recording the near-field strong ground motion will help in the more accurate determinations of the earthquake source time function and thus will improve the reliability of the near- and far-field spectra which are still the basic tools in detection work.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Source Mechanism						
Strong-Motion Seismology						
Dynamic Dislocations						
Array of Strong-Motion Accelerographs						

Security Classification

1a

Semi-Annual Technical Report (July 31, 1974)

on

Near Field Small Earthquake Strong-Motion Studies
(Contract F44620-72-C-0097)

prepared at

Earthquake Engineering Research Laboratory
California Institute of Technology

by

M. D. Trifunac

__Summary__

The objective of this research has been to improve our ability to distinguish between the explosive and tectonic energy releases in the magnitude range $3 \leq M \leq 5$. This work will help in the more accurate determinations of the earthquake source time function and thus will improve the reliability of the near- and far-field spectra which are still the basic tools in detection work.

On September 29, 1972 the Earthquake Engineering Research Laboratory completed installations of 12 strong-motion stations in Bear Valley, California. The elliptically shaped array (Figure 1) is centered along the San Andreas Fault some 30 km southeast of Hollister, California.

From the records obtained by the network, the near-field accelerations, velocities, and displacements of ground will be obtained. By fitting theoretical spectra to these observations, the effective stress and other source parameters will be derived. The strong-motion

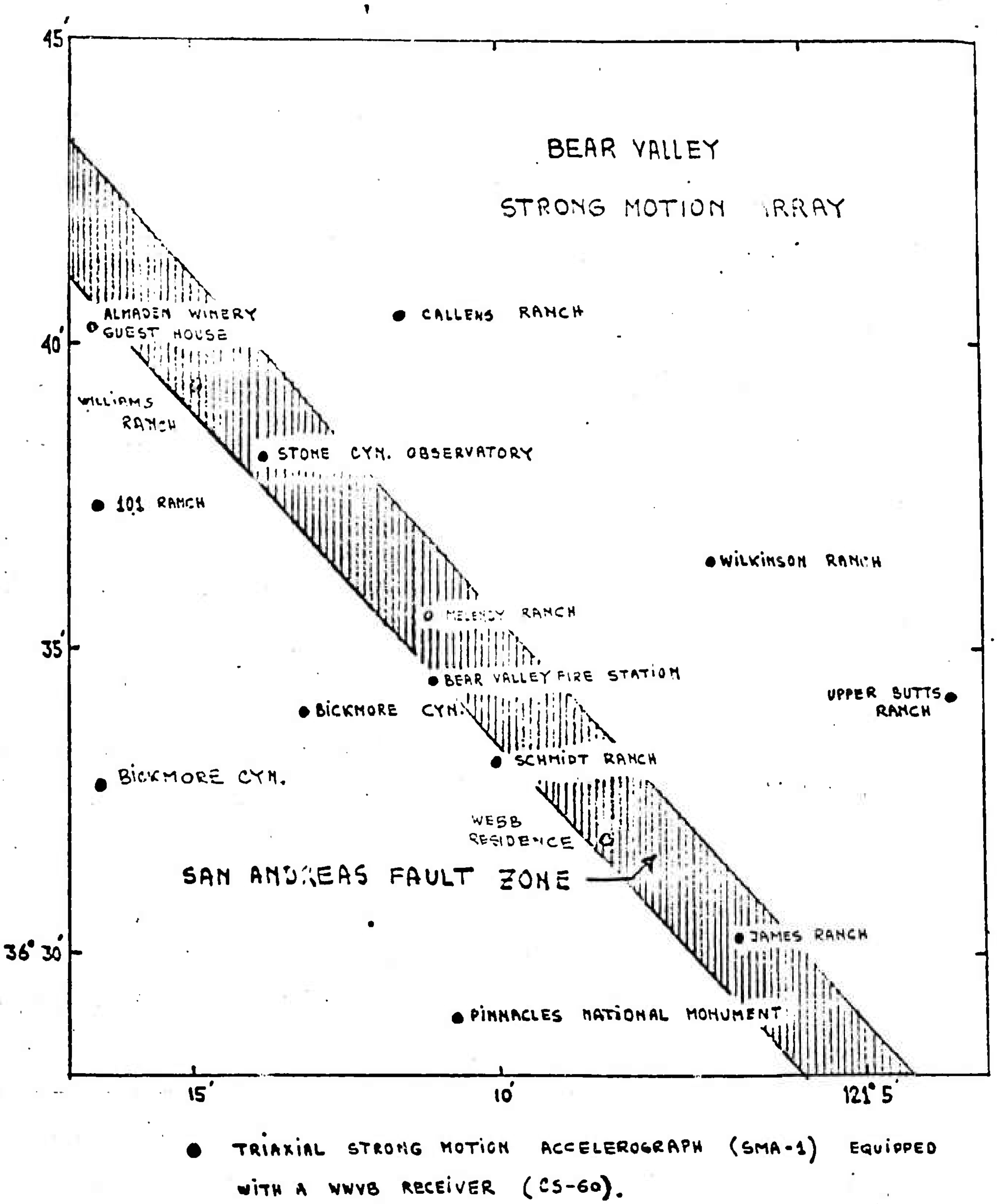

BEAR VALLEY
STRONG MOTION ARRAY
ALMADEN WINERY GUEST HOUSE
CALLENS RANCH
WILLIAMS RANCH
STONE CYN. OBSERVATORY
101 RANCH
WILKINSON RANCH
MELENDY RANCH
BEAR VALLEY FIRE STATION
UPPER BUTTS RANCH
BICKMORE CYN.
SCHMIDT RANCH
BICKMORE CYN.
WEBB RESIDENCE
SAN ANDREAS FAULT ZONE
JAMES RANCH
PINNACLES NATIONAL MONUMENT
45'
40'
35'
36° 30'
15'
10'
121° 5'
● TRIAXIAL STRONG MOTION ACCELEROGRAPH (SMA-1) EQUIPPED WITH A WWVB RECEIVER (CS-60).

Figure 1

network will provide a means to observe the flux of seismic energy away from the source and to study the detailed nature of the pattern of energy release. These measurements will be compared to the far-field measurements obtained by other study groups in this program and the effects of the path on seismic waves will thus be determined. In this way the accuracy of information desired from distant stations can be critically examined, tested, and complemented. In addition, the strong-motion network will furnish important clues to the rupture velocity, one of the most poorly known source parameters.

The data from five strong-motion accelerograph stations centered above and surrounding the fault have been used to develop an approximate three-dimensional dislocation model for the San Fernando earthquake $M_L = 6.4$ (Figure 2) (Trifunac, 1974). In the resulting model the dislocation originates near the instrumentally determined epicenter at a depth of 9.2 km and then propagates southwards and upwards with a velocity of 2 km/sec. Calculated dislocation amplitudes of about 10 m in the hypocentral region have been found to decay to about 1 m towards the center of the fault and then build up again to about 6 m just before the fault intersects the ground surface in the San Fernando Valley. The assumed fault area of 130 km^2 and the assumed rigidity $\mu = 3 \times 10^{11}$ dyne/cm^2 give a moment $M_0 =$ 1.53×10^{26} dyne-cm. This study indicates that with several strong-motion accelerographs suitably located in the epicentral region it is possible to find a detailed kinematic faulting process.

Recordings from five strong-motion accelerograph stations have been used to derive a three-dimensional dislocation model for the

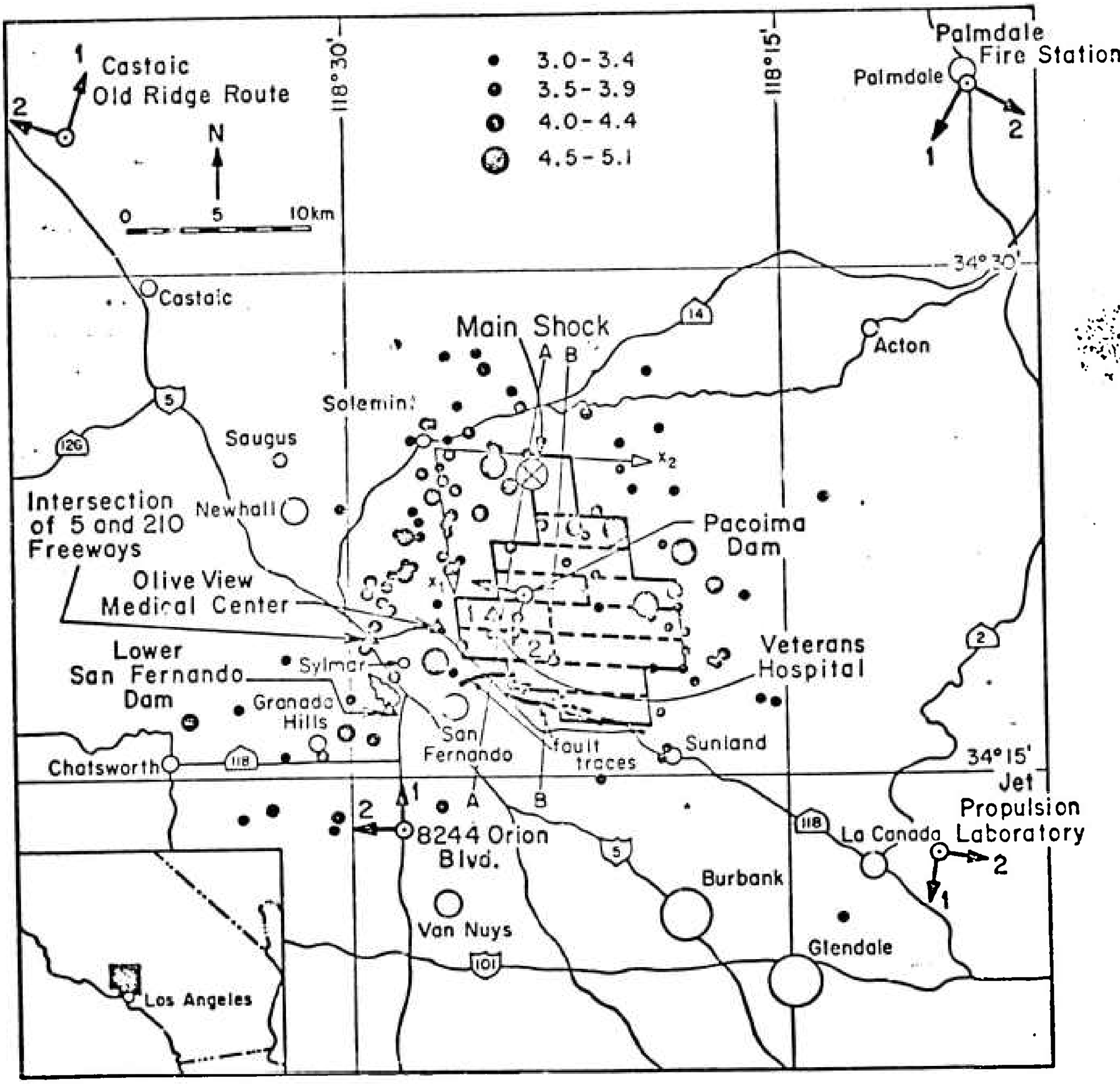

1
Castaic
Old Ridge Route
2
118°30'
3.0 - 3.4
3.5 - 3.9
4.0 - 4.4
4.5 - 5.1
118°15'
Palmdale
Fire Station
Palmdale
N
0
5
10km
34°30'
Castaic
14
Main Shock
A B
Acton
5
Solemint
126
Saugus
x2
Intersection
of 5 and 210
Freeways
Newhall
Pacoima
Dam
Olive View
Medical Center
x1
Lower
San Fernando
Dam
Sylmar
Veterans
Hospital
2
Granada
Hills
San
Fernando
fault
traces
Sunland
Chatsworth
118
34°15'
1
A
B
Jet
Propulsion
Laboratory
2
8244 Orion
Blvd.
118
La Canada
2
1
5
Burbank
Van Nuys
Glendale
Los Angeles
101

Figure 2

Parkfield Earthquake, $M_L = 5.8$ (Trifunac and Udwadia, 1974). The model consists of a buried fault which extends from a depth of 3 km to a depth of 9 km below the ground surface (Figure 3). It appears from the analysis, which considers various fault lengths, that the zone of significant faulting was the twenty kilometer long northwestern section of the fault. The rupture velocity has been found to be between 2.4 and 2.5 km/sec and the dislocation amplitudes have been found to be about 120 cm. There have been comparisons made of the model results with geodetic data on static deformations and creep measurements following the event. In contrast with several other source mechanism studies of the Parkfield event, this model yields a picture which appears to be very consistent with both the dynamic strong motion measurements as well as the available geodetic and creep data.

The Bear Valley, California, Earthquake of June 22, 1973 has been recorded at 10 strong motion stations of the Bear Valley array. Five stations surrounding the epicenter have been selected for further study and are shown in Figure 4. They surround the epicenter and provide adequate coverage for detailed source mechanism study. Preliminary work based on the three dimensional Haskell's (1969) model has indicated that this earthquake could be described by a rectangular fault $\frac{1}{2}$ by $\frac{1}{2}$ kilometers and at a depth of 10 km. A right-lateral fault could be characterized by an average dislocation of about 1 m and dislocation velocity of 3.0 km/yr.

ARRAY MAP SHOWING LOCATIONS OF ACCELEROGRAPHS, SEISMOSCOPES, AND FAULT ZONE

Parkfield Earthquake

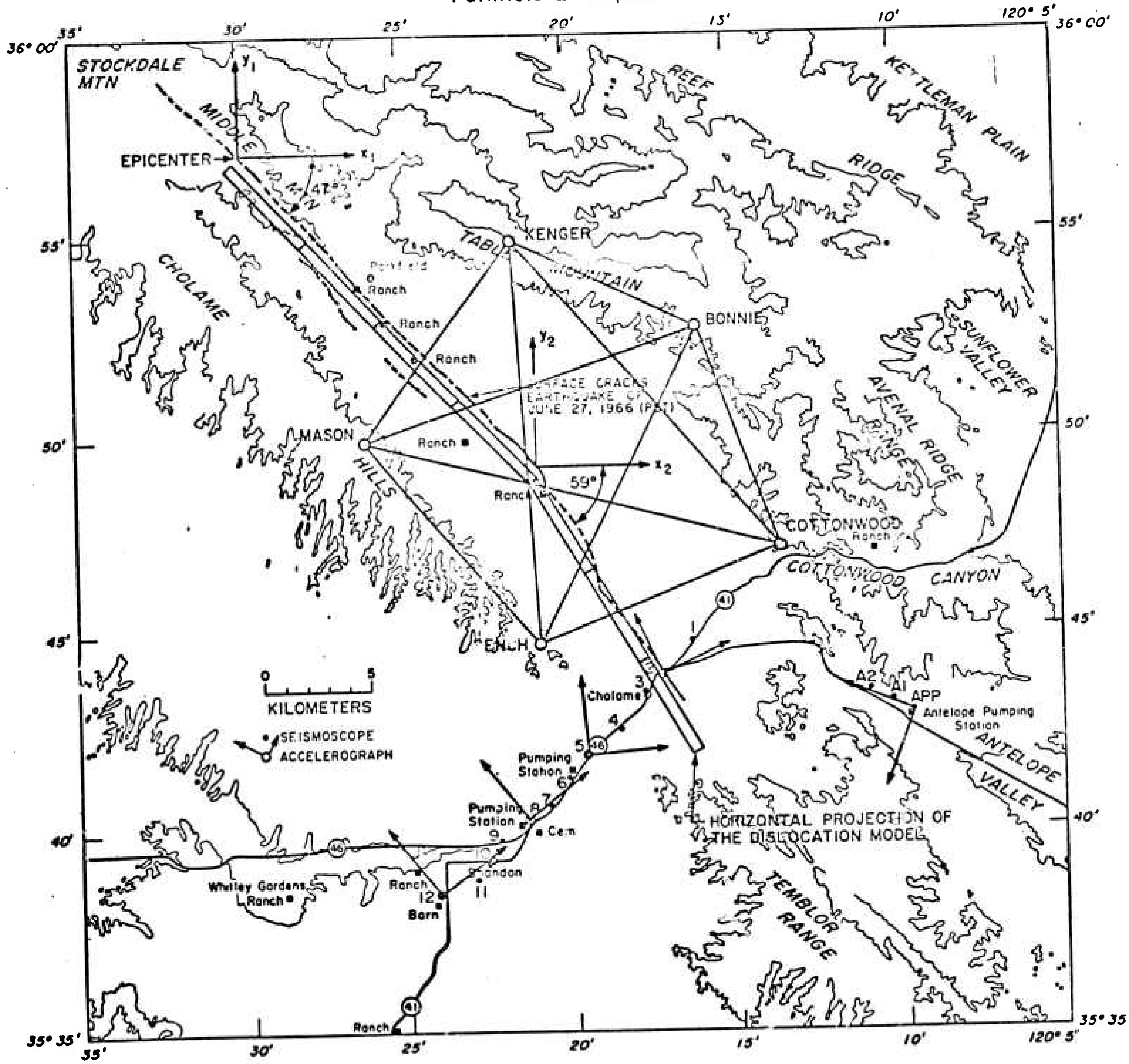
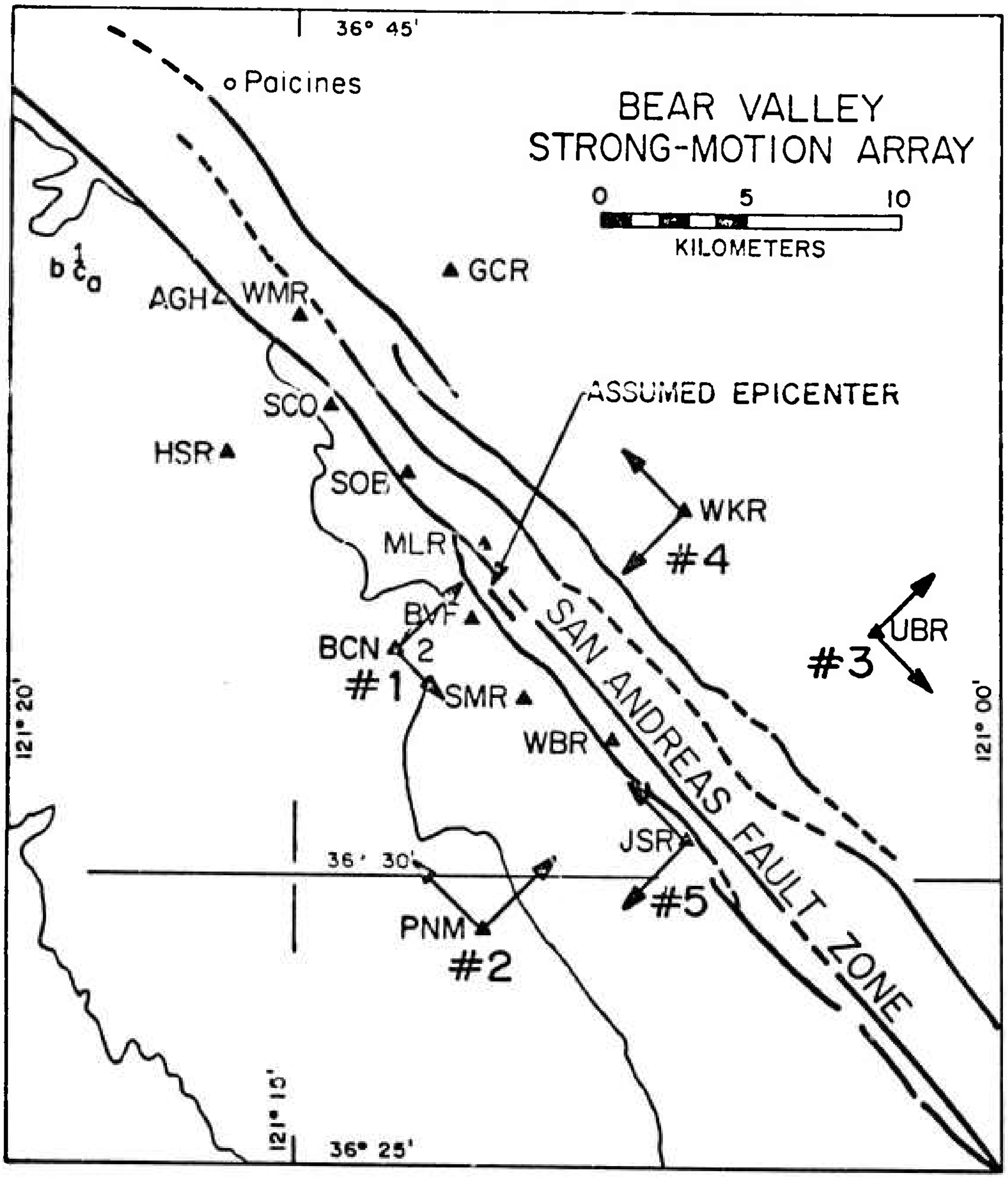


Figure 3



36° 45'
Paicines
BEAR VALLEY
STRONG-MOTION ARRAY
0
5
10
KILOMETERS
GCR
AGH
WMR
SCO
HSR
SOB
ASSUMED EPICENTER
WKR
#4
MLR
BVF
BCN
2
#1
SMR
UBR
#3
WBR
SAN ANDREAS FAULT ZONE
JSR
36° 30'
PNM
#2
#5
121° 20'
121° 00'
121° 15'
36° 25'

Figure 4

Experimental Program and Major Accomplishments

Seven field trips were made. During the first trip (26-29 July 1972) the Bear Valley area was explored and the tentative sites for strong-motion stations were selected. During the second trip (18-29 September 1972) twelve strong-motion stations were installed and have been operating since 29 September 1972). A typical station consists of one triaxial strong-motion accelerograph (SMA-1 type), manufactured by Kinemetrics, Inc., and a WWVB receiver providing the absolute time. The SMA-1 accelerograph provides accurate information about the strong-motion acceleration in the frequency range between 0.06 and 25 cps. It is expected that an earthquake of magnitude ≥ 4 occurring in the middle of the array will trigger all instruments.

During the third field trip (6-9 January 1973) stations Bickmore Canyon, Pinnacles National Monument, Scmidt Ranch, James Ranch, Stone Canyon Observatory, Bear Valley Fire Station, Almaden Guest House, and Callens' Ranch (Figure 1) were revisited for routine checkup and maintenance work. Weather conditions did not permit access to the four stations: Melendy Ranch, 101 Ranch, Wilkinson Ranch, and Butts Ranch.

During the fourth field trip (16-23 June 1973) all stations of the array were revisited for routine checkup and maintenance work; including the four stations: Melendy Ranch, 101 Ranch, Wilkinson Ranch, and Butts Ranch that could not be inspected during the third field trip because of poor weather conditions. Newly designed loop antennas were fitted to all stations because the original design did not appear to be fully water proof.

During the fifth trip (September 21-28, 1973) all stations were revisited and serviced. The acceleration records from all stations, excluding Stone Canyon Observatory and Almaden Winery Guest House, were collected. Accelerograph at the Stone Canyon Observatory site was moved to a new, nearby location to improve the noisy WWVB radio signal. New stations at Webb residence and Williams Ranch were installed.

During the sixth trip (December 10-17, 1973) all stations were revisited and serviced. The fifteenth station was installed in the Bickmore Canyon.

Review of the Existing Data

The understanding of the detailed nature of spatial and temporal behavior of earthquake and explosion source mechanisms seems to us to be the key for the full development and refinement of the M_s-m_b discriminant as well as several other discrimination techniques. Since the near-field accelerograms can be used to decipher fine details of the pattern of the earthquake energy release in time and space (Trifunac and Brune, 1970; Trifunac, 1972a, b; Trifunac, 1974; Trifunac and Udwadia, 1974), we feel that this is a unique opportunity to fully exploit the existing information in the strong-motion accelerograms already recorded. To this end we are at present actively engaged in processing numerous strong-motion accelerograms and analyzing several of them that appear to be the most significant from the discrimination point of view.

We have examined the three-dimensional dislocation model described by Haskell (1969) as a possible basis for modeling the earthquake fracture process. Using the data from five strong-motion stations surrounding the fault zone of the San Fernando, California, Earthquake of February 9, 1971 (Figure it has been possible to find a model (Figure 5) which approximately correlates with the recorded ground displacements during the earthquake (strong-motion data, Figure 6) with the static deformations after the earthquake (geodetic data, Figure 7) and with the observed faulting in the San Fernando Tujunga area.

Finding the dislocation model for a given earthquake from strong-motion data is a difficult task involving the solution of an inverse problem which has no unique solution. The problem is further complicated by the effects of non-homogeneous media between the source and the receiver. It appears, however, that by recording the ground motion at distances less than one source dimension, it may be possible to derive a simple approximate source model that can satisfy the dynamic and static measurements of the earthquake effects in the low frequency band from D. C. to about 1 cps. For this frequency band the amplitudes of recorded waves are believed not to be affected seriously by the local geologic conditions.

In our continuing effort to extend this approach to smaller magnitude earthquakes, we studied the Parkfield, California, Earthquake of 1966 and found that detailed interpretation of the recorded ground motions is possible when three-dimensional Haskell's representation is used (Trifunac and Udwadia, 1974). Our future work will be devoted to an extension of this technique to smaller magnitude shocks.

DISLOCATION AMPLITUDES ON THE SAN FERNANDO FAULT
EARTHQUAKE OF FEBRUARY 9, 1971

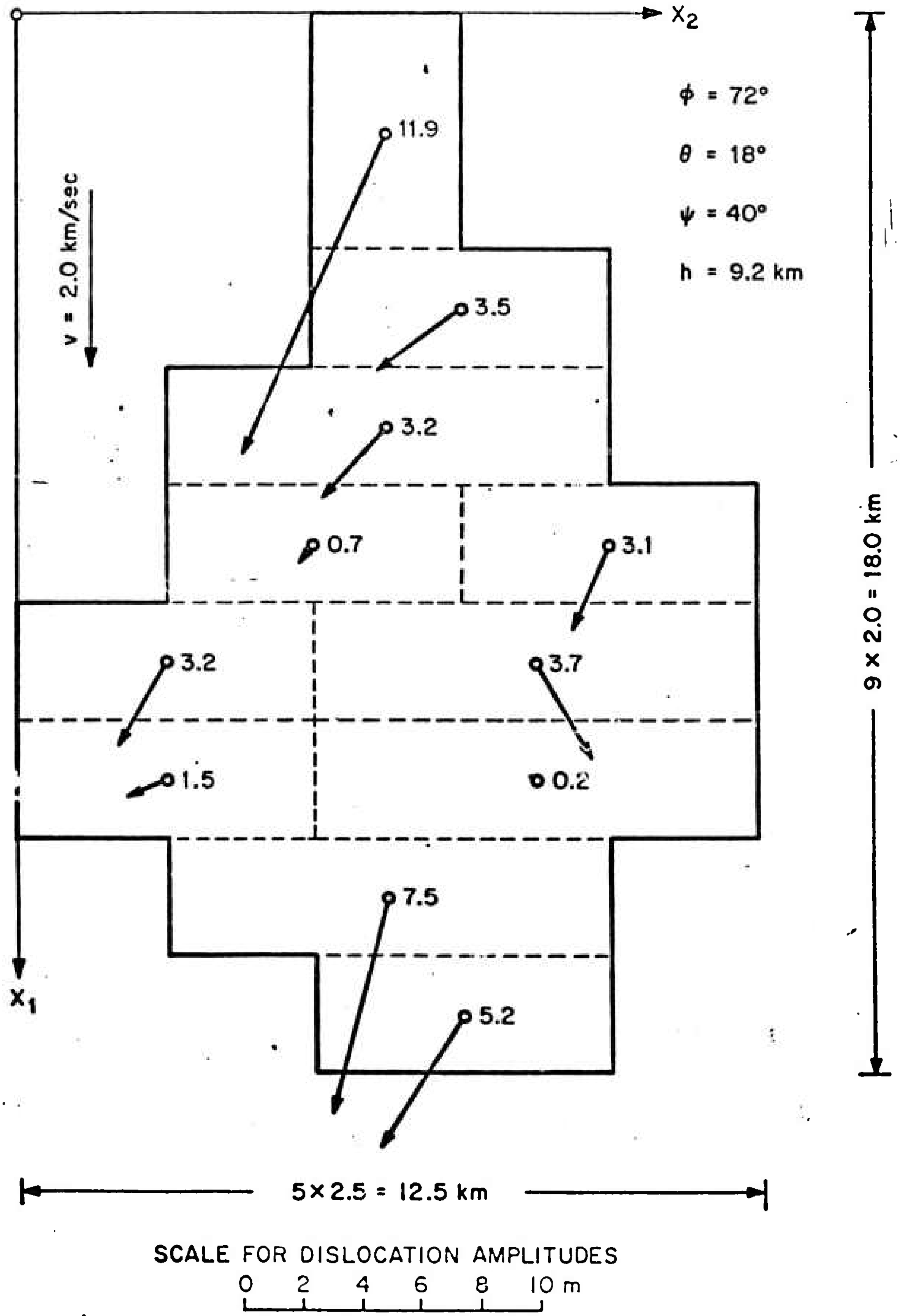


Figure 5

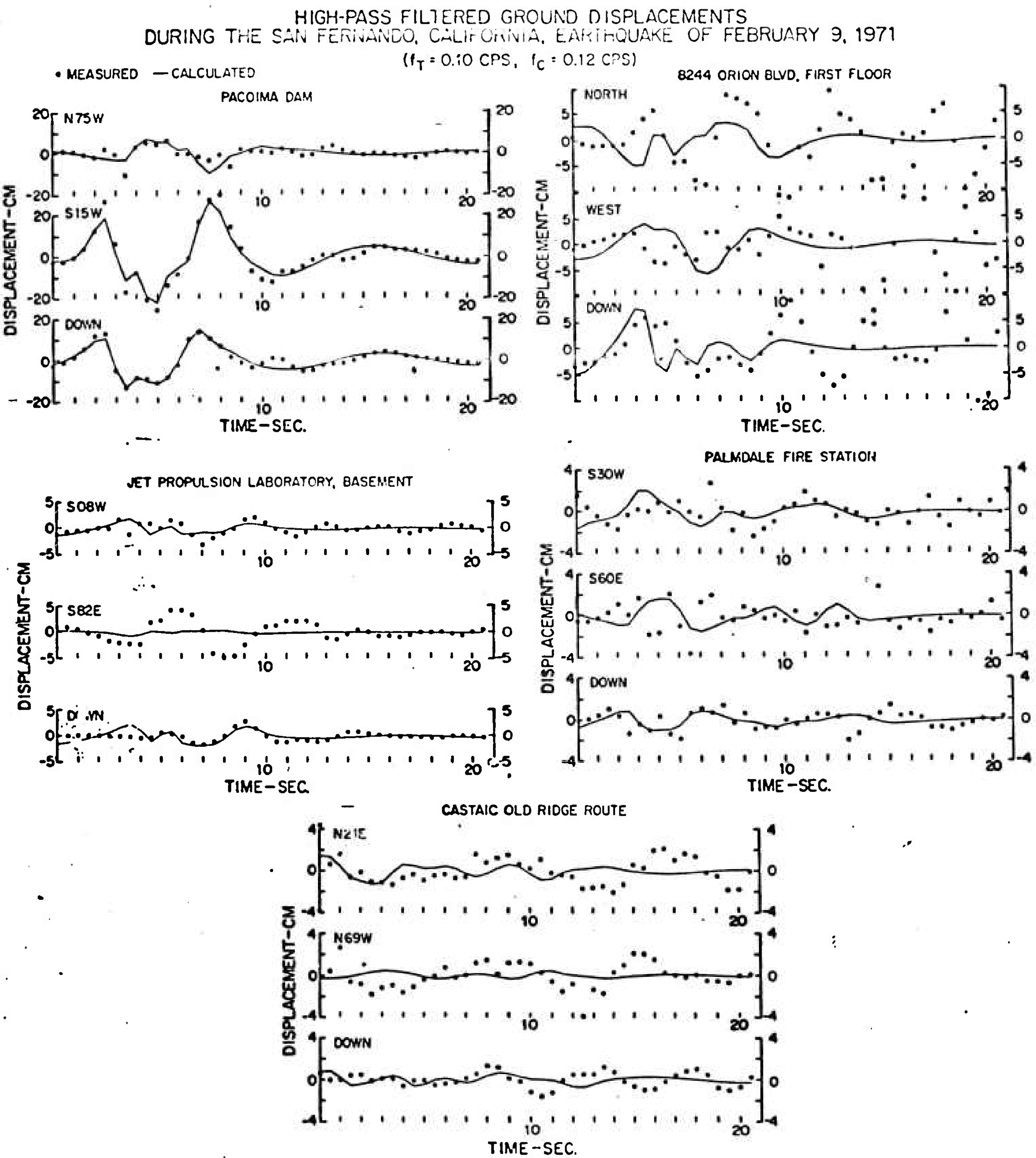

HIGH-PASS FILTERED GROUND DISPLACEMENTS
DURING THE SAN FERNANDO, CALIFORNIA, EARTHQUAKE OF FEBRUARY 9, 1971
(f_T = 0.10 CPS, f_C = 0.12 CPS)
• MEASURED — CALCULATED
PACOIMA DAM
N75W
S15W
DOWN
DISPLACEMENT-CM
TIME-SEC.
8244 ORION BLVD. FIRST FLOOR
NORTH
WEST
DOWN
JET PROPULSION LABORATORY, BASEMENT
S08W
S82E
PALMDALE FIRE STATION
S30W
S60E
CASTAIC OLD RIDGE ROUTE
N21E
N69W

Figure 6

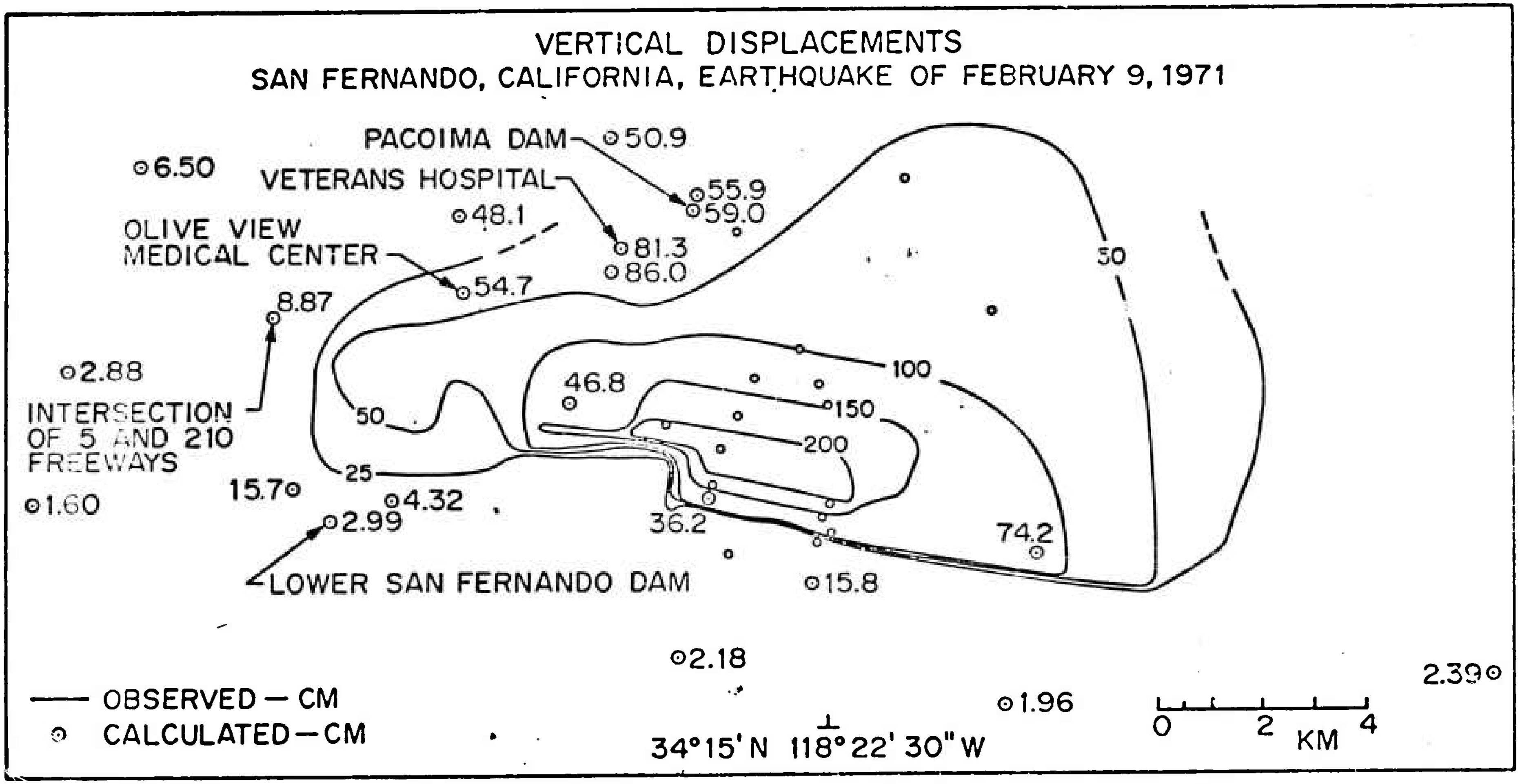

VERTICAL DISPLACEMENTS
SAN FERNANDO, CALIFORNIA, EARTHQUAKE OF FEBRUARY 9, 1971
PACOIMA DAM
50.9
VETERANS HOSPITAL
55.9
59.0
6.50
48.1
OLIVE VIEW
MEDICAL CENTER
81.3
86.0
54.7
8.87
50
2.88
100
46.8
150
INTERSECTION
OF 5 AND 210
FREEWAYS
50
200
25
15.7
4.32
1.60
2.99
36.2
74.2
LOWER SAN FERNANDO DAM
15.8
2.18
2.39
OBSERVED — CM
CALCULATED — CM
1.96
0
2
KM
4
34°15' N 118°22' 30" W

Figure 7

The Bear Valley, California, Earthquake of June 22, 1973 provided the first such opportunity. The magnitude of the shock was reported as M = 3.9, which is close to the threshold level below which it is quite difficult to record accurately strong-ground motion with conventional accelerographs. Nevertheless we obtained ten excellent accelerograms (Dielman, et al., 1975). Five stations that surround the epicenter have been selected for further three-dimensional dislocation studies. Preliminary results have indicated that it may be possible to match the recorded with the synthetic near field and body wave contributions quite accurately. Figure 8 shows an example of a good fit at station no. 1 (Fig. 4), which is located in the basement rock southwest of the epicenter. The quality of fit is not so good for stations no. 3 and no. 4 because these stations are located on the sedimentary deposits which filter the incident motions appreciably.

To see how the approximate solution, least square fitted to the observed data, agrees with the exact dislocation model we have to wait until such time as when it will be possible to measure dislocation amplitudes at the fault itself. The present analysis shows, however, that until that time comes it is worthwhile to (1) develop the representation of the dynamic dislocation models in non-homogeneous half-space and (2) deploy arrays of strong-motion accelerographs to measure the near-field strong ground motion. The results of this preliminary analysis already indicate the possibility of deciphering the details of the complicated dislocation processes and demonstrate how valuable the near-field strong-motion data are for acquiring an understanding

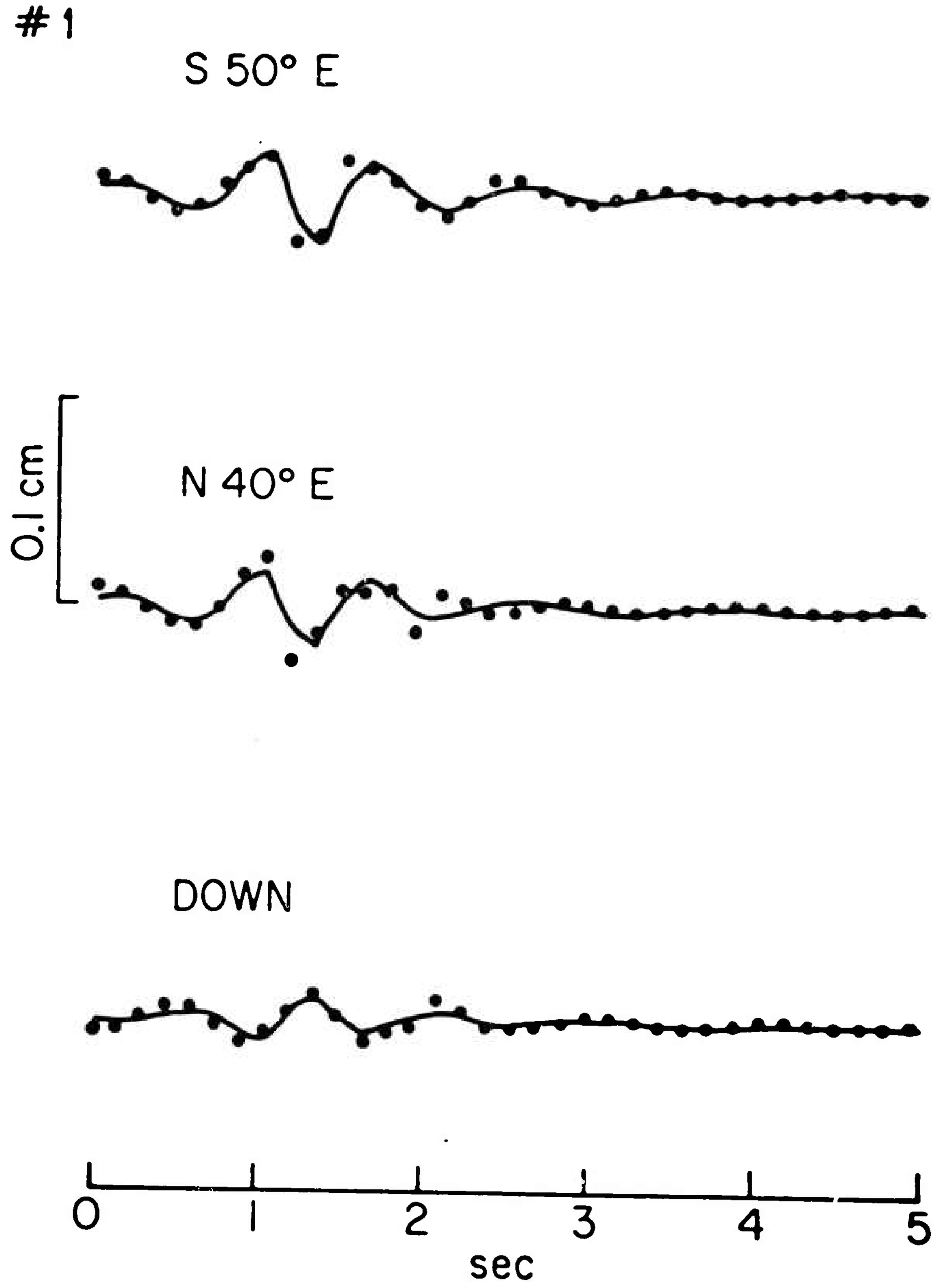


Figure 8

of earthquake source mechanism, of prediction of strong ground shaking for earthquake engineering purposes and for the development of sensitive techniques for discrimination between explosive and tectonic sources.

Under Caltech's subcontract (#28-88797C), Dr. Max Wyss of CIRES and the University of Colorado, investigated the possible improvements in the derivation of the source parameters from S-waves. To derive the S-wave source-spectrum a clean S recording is needed. This, however, is in general not available. On records near the source the S-phase is immediately followed by surface waves (Love and Rayleigh). At larger distances the S-pulse is followed by S coupled PL waves. These are a type of surface wave generated near the receiver. The problem studied in this work was to determine the difference between PL contaminated and uncontaminated S time series and spectra, as well as the difference in the source dimension and moment estimated from the spectra.

It was found by Dr. Wyss that the PL contaminated SV results deviate by approximately 30 percent from the P and SH results. In addition, the source dimension, r, and the seismic moment, M_o, estimates from SV have a larger RMS error and suffer more from subjective interpretation of the spectra. M_o and r estimates based on EW or NS components alone would be afflicted by subjectiveness and errors equal or somewhat less than those in the case of estimates based on SV.

The results of this work were presented at the National Meeting of the Seismological Society in Golden, Colorado, May 1973.

REFERENCES

Dielman, R. J., T. C. Hanks and M. D. Trifunac (1975). An Array of Strong Motion Accelerographs in Bear Valley, California, Bull. Seism. Soc. Amer., 65, (in press).

Haskell, N. A. (1969). Elastic Displacements in the Near-Field of a Propagating Fault, Bull. Seism. Soc. Amer., 59, 865-903.

Trifunac, M. D. and J. N. Brune (1970). Complexity of Energy Release during the Imperial Valley, California, Earthquake of 1940, Bull. Seism. Soc. Amer., 60, 137-160.

Trifunac, M. D. (1972a). Stress Estimates for San Fernando, California, Earthquake of 9 February 1971: Main Event and Thirteen Aftershocks, Bull. Seism. Soc. Amer., 62, 721-750.

Trifunac, M. D. (1972b). Tectonic Stress and Source Mechanism of the Imperial Valley, California, Earthquake of 1940, Bull. Seism. Soc. Amer., 62, 1283-1302.

Trifunac, M. D. (1974). A Three-Dimensional Dislocation Model for the San Fernando, California, Earthquake of February 9, 1971, Bull. Seism. Soc. Amer. (in press).

Trifunac, M. D. and F. E. Udwadia (1974). Parkfield, California, Earthquake of June 17, 1966: A Three-Dimensional Moving Dislocation, Bull. Seism. Soc. Amer. (in press).